Distributed Embedded Real-Time Agent Resource Management

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Abstract:

This presentation describes an embedded intelligent agent architecture for distributing the real-time allocation and management of resources throughout networked systems. The solution is general purpose, and has been developed for several applications, including shared electronic systems and spectrum allocation. The agent architecture was derived from a combination of prior agent and resource management developments from Lockheed Martin ATL.

To guide development and evaluate the distributed agent concept prior to detailed implementations, simulation models were constructed. A successful agent architecture was derived which relies on agent to agent negotiation for resolving allocation decisions in a distributed and parallel context. The simulations led to new methods for developing agents having sufficiently small program code and data structures consistent with embeddable implementations. Further developments led to highly scalable computing solutions.

On DARPA's Next Generation Communications (XG-Comms) project, the agent technology was studied to leverage Software Defined Radios (SDR) and related emerging wireless systems of the future, for improving total spectrum utilization, especially for the continuously changing heavy traffic on the battlefield.

The XG-Comms program goals require re-using spectrum in time, space, frequency, and modulation, while minimizing interference to adjacent systems. The real-time distributed nature of the challenge was well suited to agent solutions. Results from the simulations of agents allocating spectrum will be shown. The simulations showed that the unique developments in the agent design enable the embedded agents to increase spectrum usage by more than 10x, while consuming less than 0.2% spectral overhead for control and negotiation under very high demanded loads.

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Embedded Distributed Real- Time Resource Management

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Challenge: Embedded Real- Time Management of Distributed Resources

- General reoccurring problem. Resources may be heterogeneous
- NP Hard – Many possible solutions; Most not sufficient.

Example Applications:

- Mission scheduling, planning, logistics, multi- sortie control of autonomous units, teams of UAV's, UGV's, UWV's, ...
- Multi- computer task scheduling, load leveling.
- Plant management, power & operations scheduling, vehicle signature control.
- Network load balancing, routing, wireless spectrum allocation.
- Carrier deck operations scheduling.
- Traffic flow management, optimization, intelligent highways.

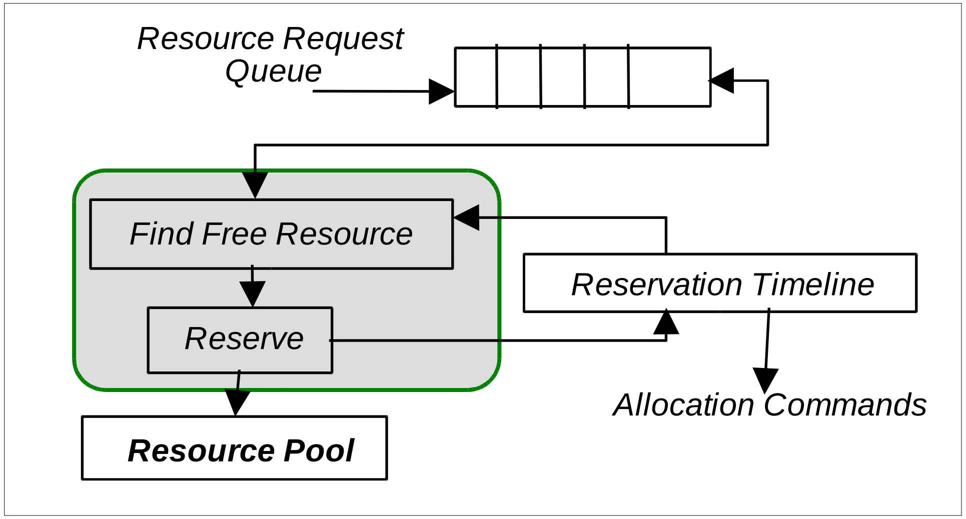
- Management ==> Continuous re- planning.

Existing Solutions:

- Bin Packing (Coffman 1998, et. al.)
- First- Fit (J. Ullman, 1973)
- Cookie- Cutter (Hoffman 1998)
- HARMONICM (JL Yowell, 1999)
- Multidimensional Bin Packing Algorithms (Kou/Markowsky '77)

Tendency: One shot, centralized, static, pre- schedule off- line.
Not intended for continuous real- time operations.

Traditional First Fit Scheduling Algorithm



Improved Methods

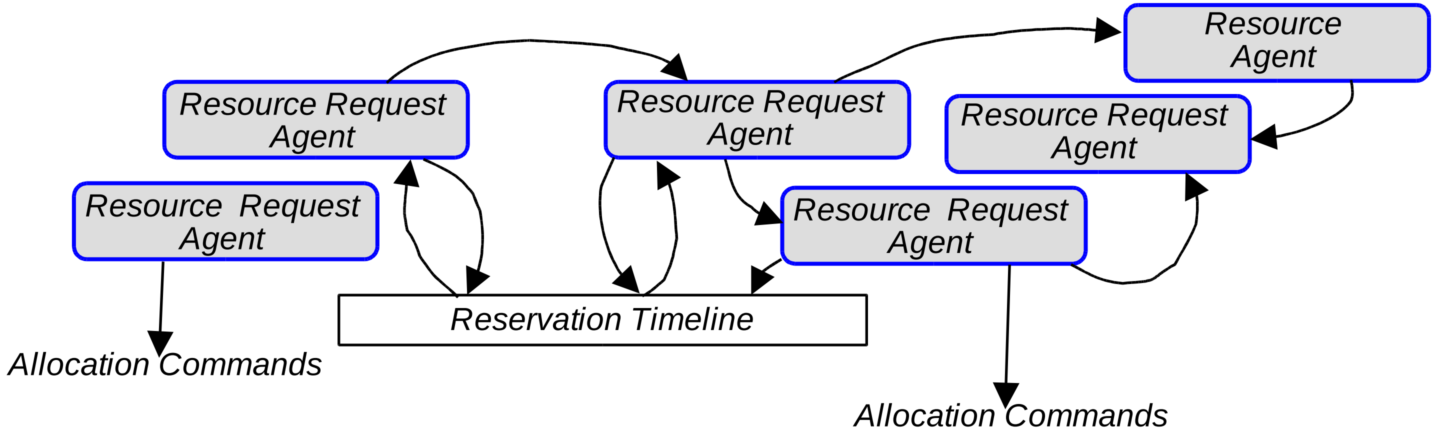
Approach:

- Leverage previous methods by distributing and extending them.
  1. Select distribution framework: *Intelligent Agents*
  2. Extend allocation algorithms within agent paradigm.

Intelligent Agent:

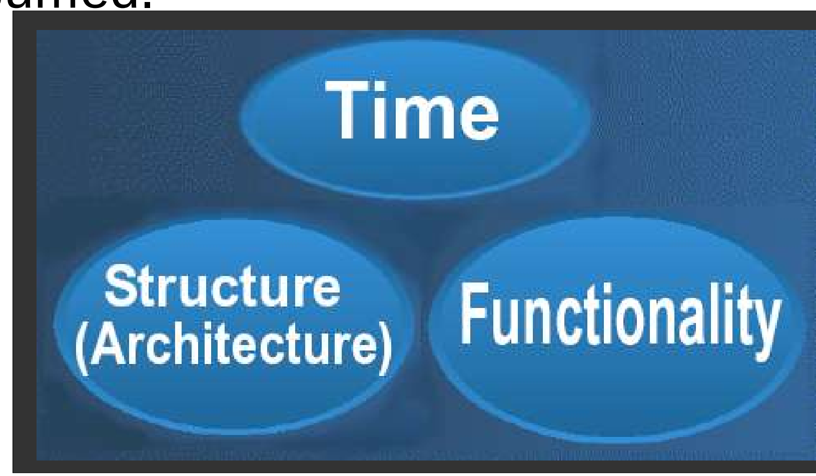
- Independent software process w/Persistence, Continual operation.
- Has perception, goals and logic to achieve goals. *Intent oriented* method.
- Serves as proxy for an application stake- holder.
- Collectively finds global solution by cooperative negotiations w/other agents.
- Light weight, embeddable, mobile.

Agent Method

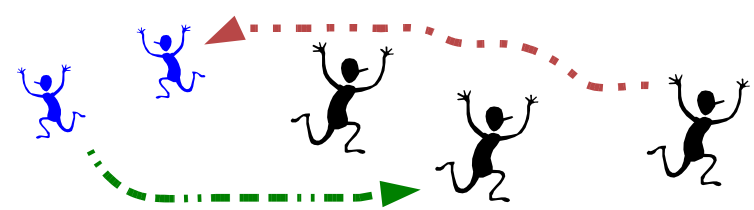


Agent & Resource Simulation Environment

- **Complex systems - - Difficult to understand.**
- Exploit modeling & simulation for rapid efficient exploration & development.
- Must investigate **Temporal, Spacial, and Functional** aspects:
  - Temporal = When resource needed or used.
  - Spatial = Where requested / consumed.
  - Functional = Express complex agent allocation rules.
- Used ATL CSIM
  - www.atl.lmco.com/proj/csim
  - Good agent simulator.
  - Multi- domains/levels with common simulator.
  - Provides mission- level context for engineering models to assess mission success impacts.



CSIM

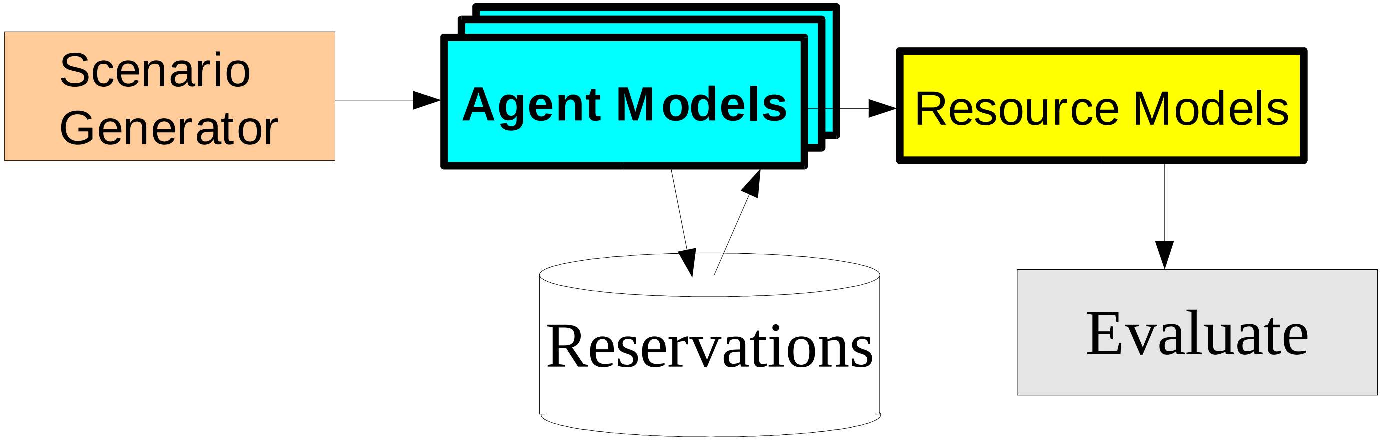


Experiments:

Metrics:

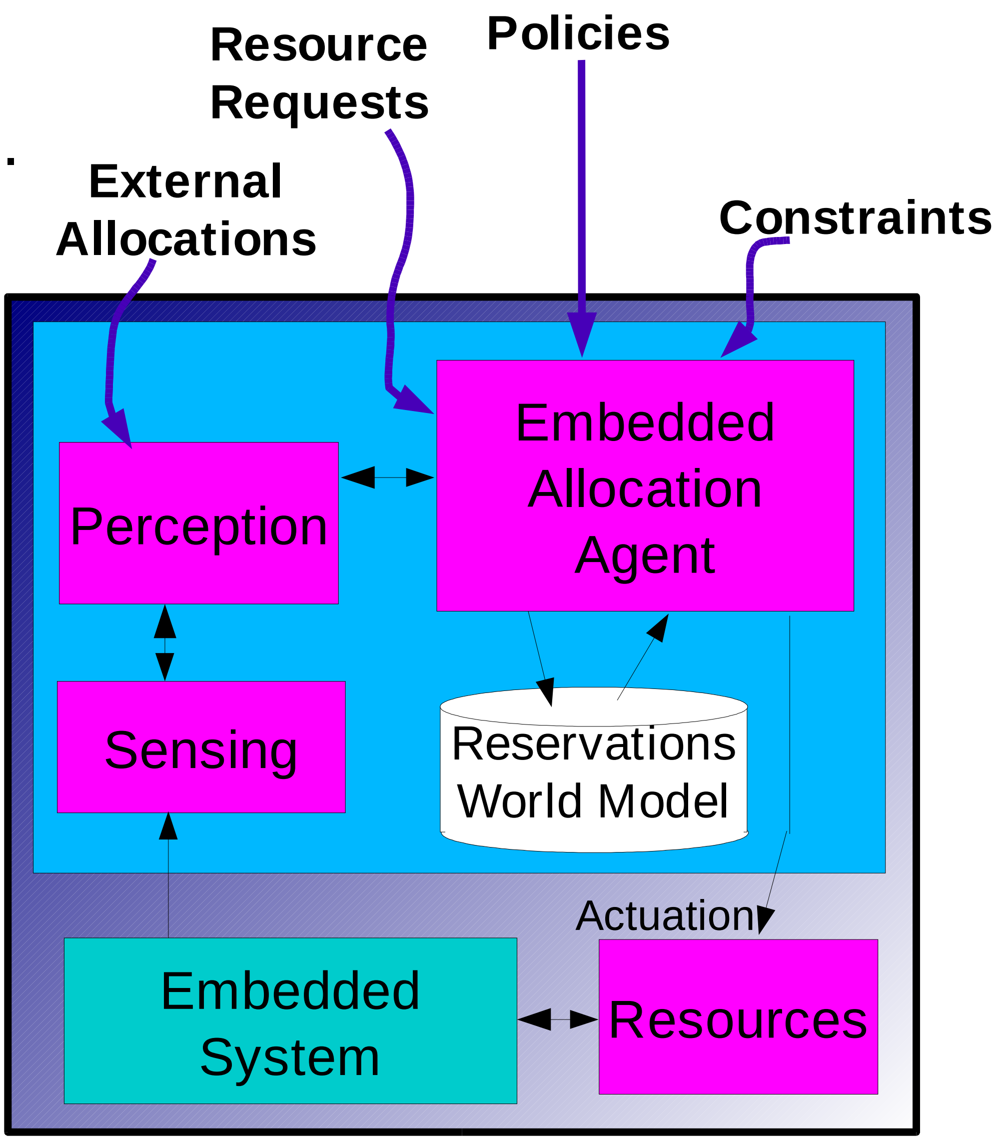
- Response Time (min, mean, max, variance)
- Overhead, agent communications (bytes/sec)
- Scalability (growth as function of complexity)

Simulation Approach:



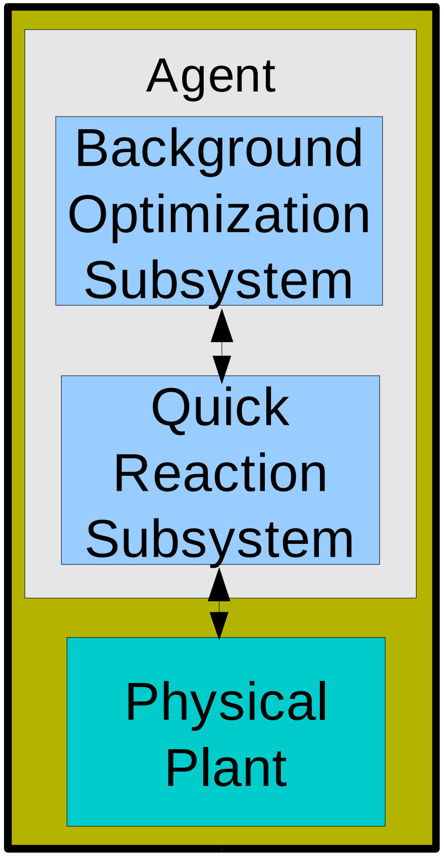
Agent Design

- Tried several approaches.
- Key discovery - - > Agents with their own internal *world models* reduce inter- agent negotiations.
- World models enable agents to test tentative future actions a priori.
- Enables continuous predictive re- planning, - - > Anticipatory optimal sequencing.



- **Dual mode operation:**
  1. Quick reaction subsystem,
  2. Background optimization subsystem.

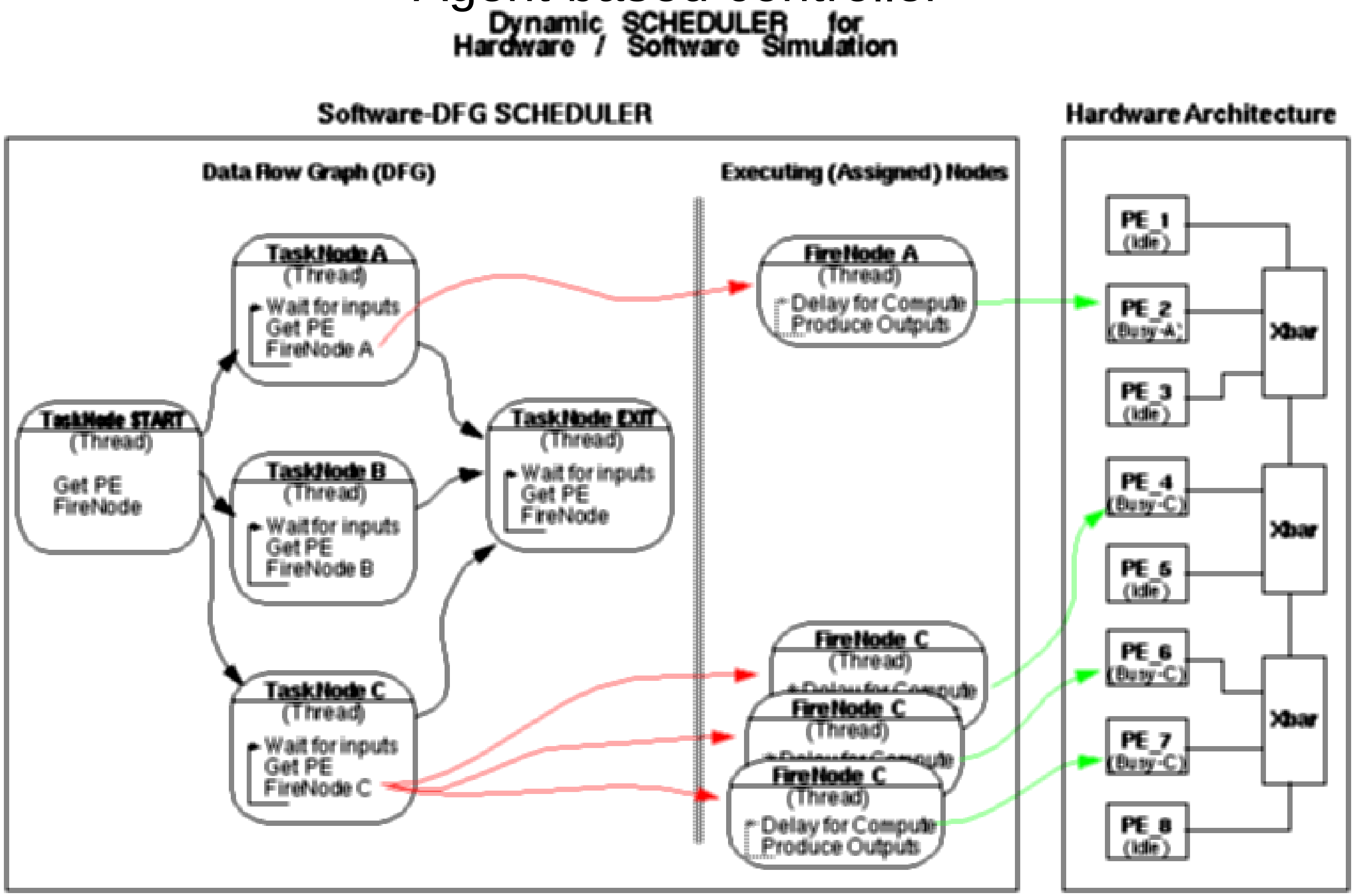
- Agents maintain own world models through observation of environment/past experience.
- Agent considers decision alternatives by simulating outcome on internal model.
- Requires lightweight, portable, embeddable simulator such as CSIM.
- During simulations in CSIM, agents launch their own *mini- simulations* within virtual world.



Application Example 1

Agents Applied to Real- Time Software Task Scheduler

Agent based controller



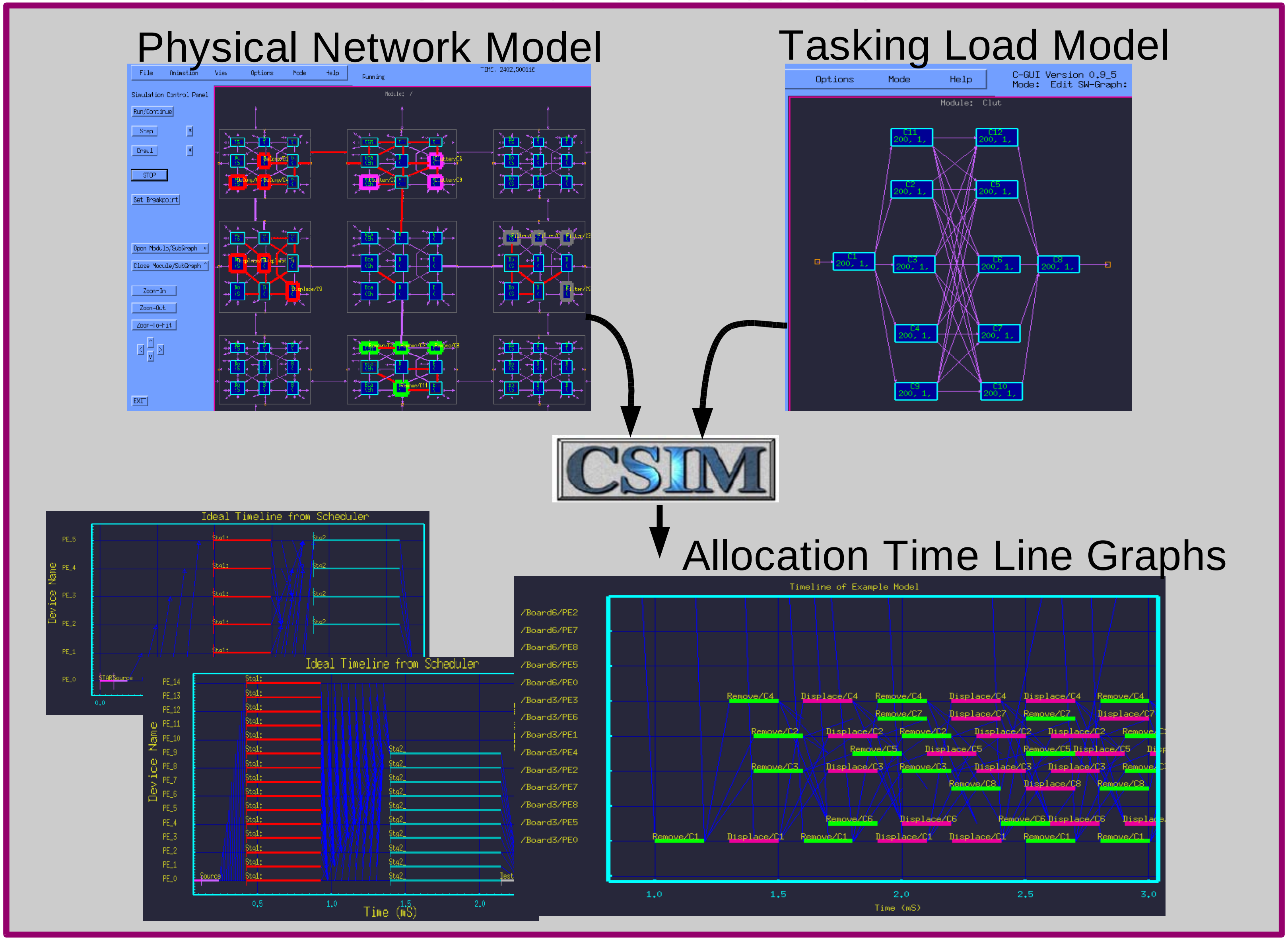
Task Management Agents

Execution Management Agents

Physical Hardware System

Application Example 1

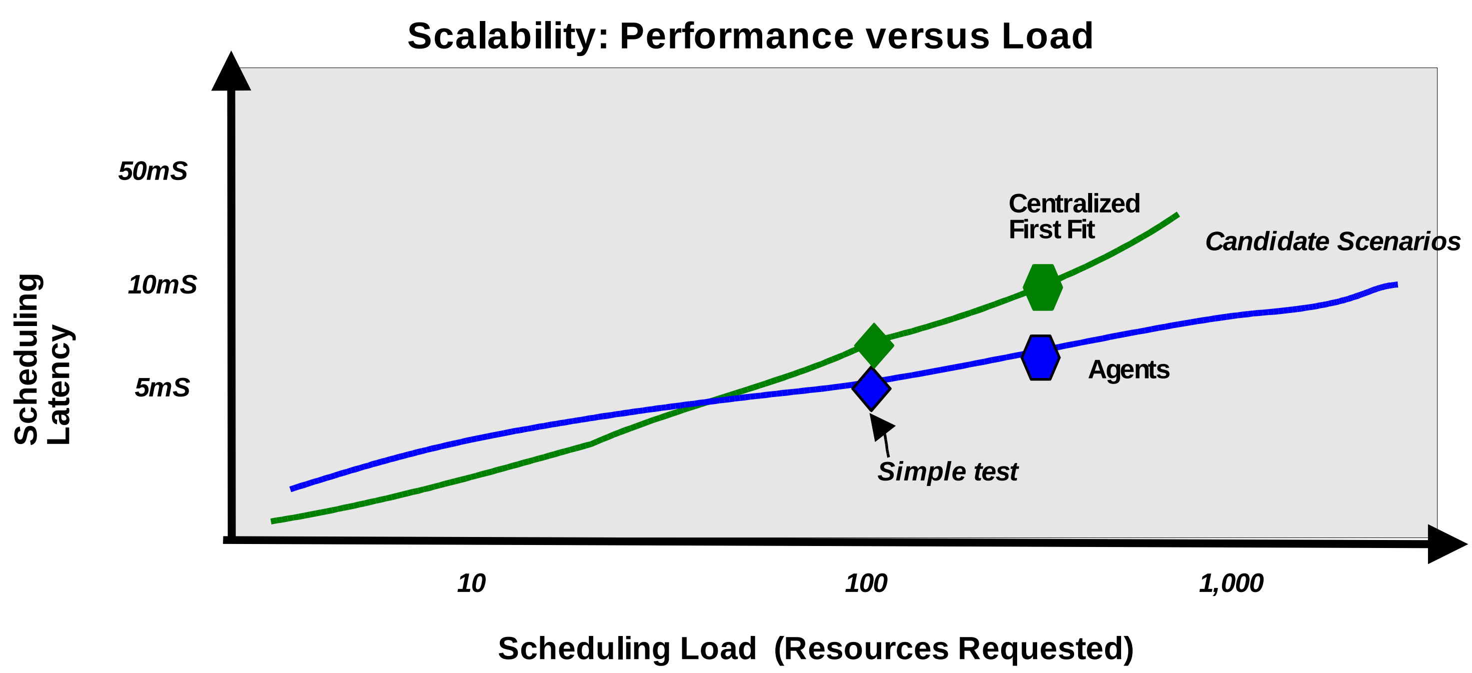
Simulation Process



Application Example 1

Application Results:

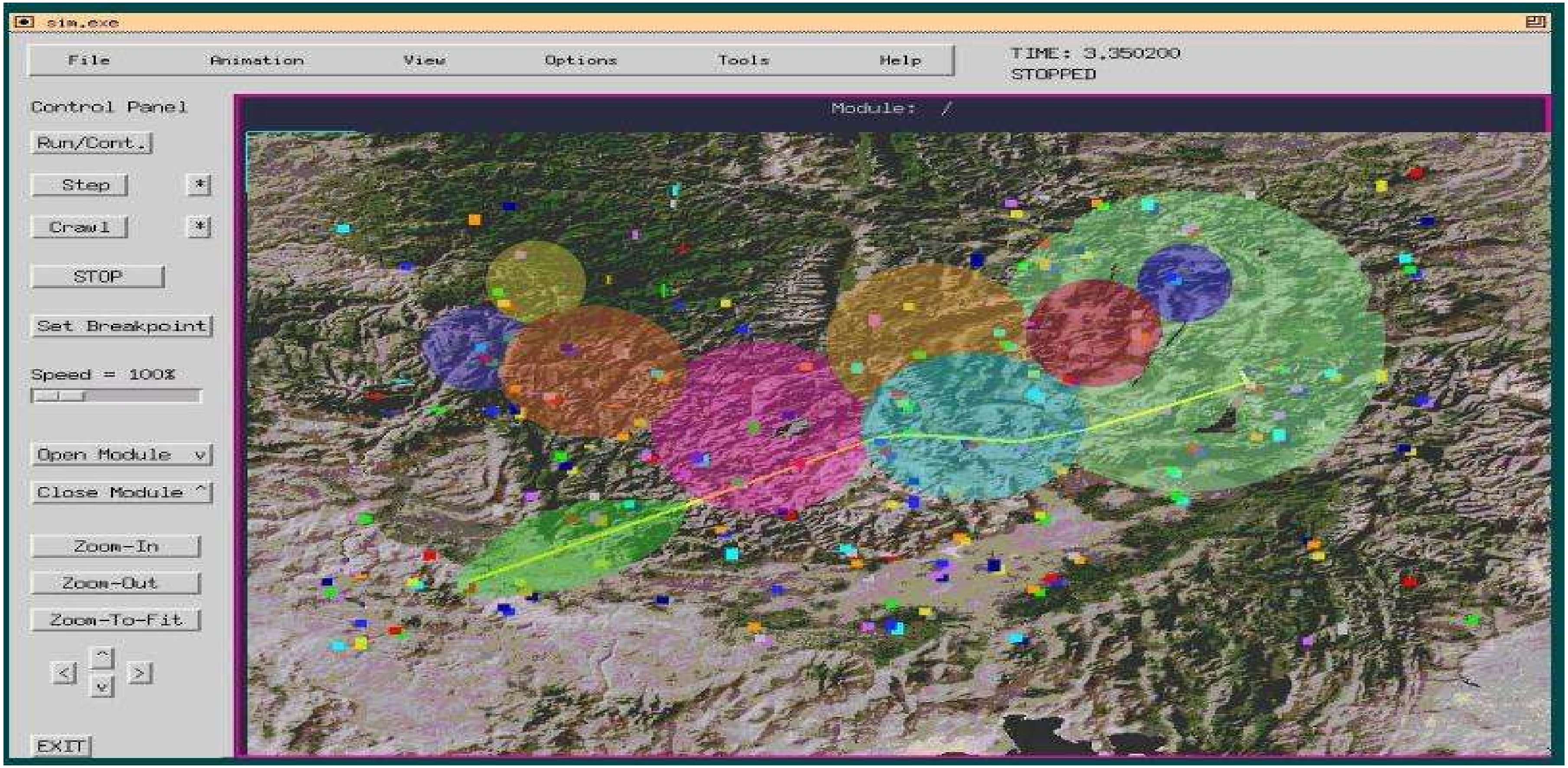
- Combination of advanced algorithms found to enable efficient distributed operation.
- Neither agent paradigm by itself, nor advanced algorithms alone could account for improvement individually, but only in combination.
- Greater scalability indicated for new approach on applied scenarios.



Application Example 2

Next Generation Communications - (XG Comms)

- DARPA program to demonstrate 10x > usable wireless spectrum.
- Spectrum is presently allocated statically, centrally, but not efficiently.
- All spectrum is allocated. Little occupied at any one time or place.
- Is multi- dimensional (Time, Freq, Area, Modul) dynamic allocation app.



Application Example 2

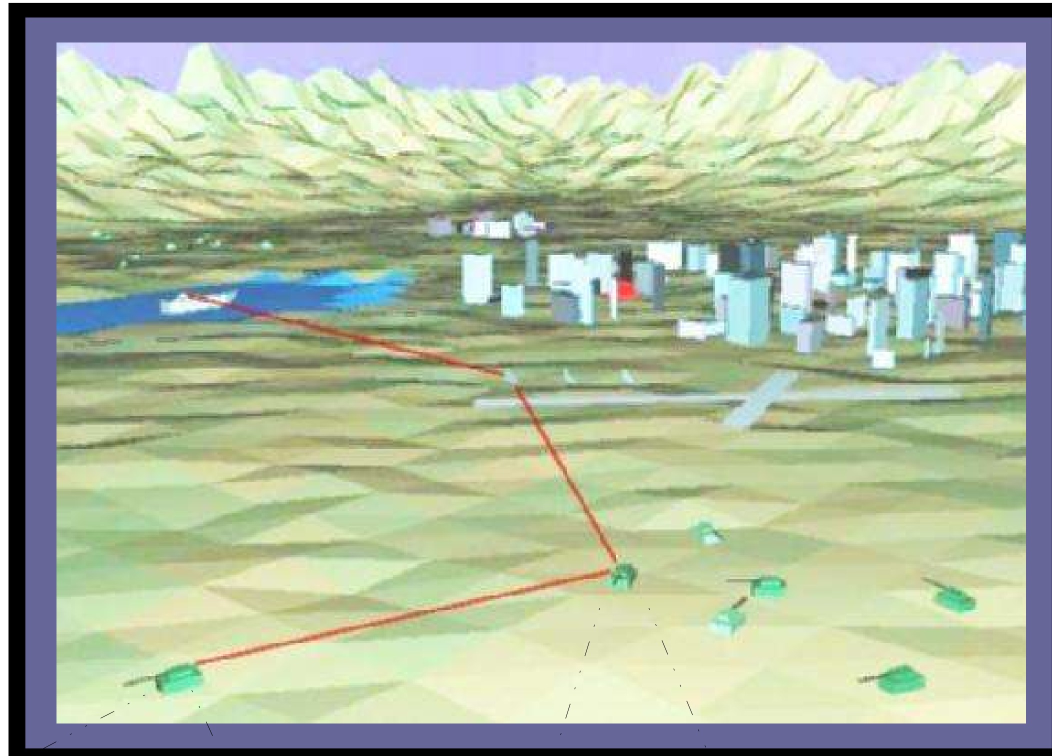
Spectrum Management

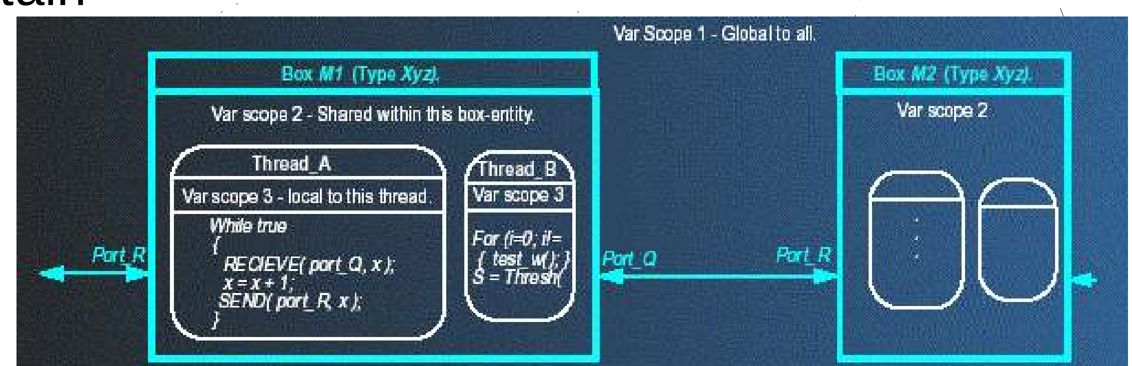
- CSIM Simulations at multiple simultaneous levels.

- Enable agent interaction in realistic mission scenarios.

- Multi- view visualizations aid understanding.

- Agent models under each vehicle model, contain agent submodels.

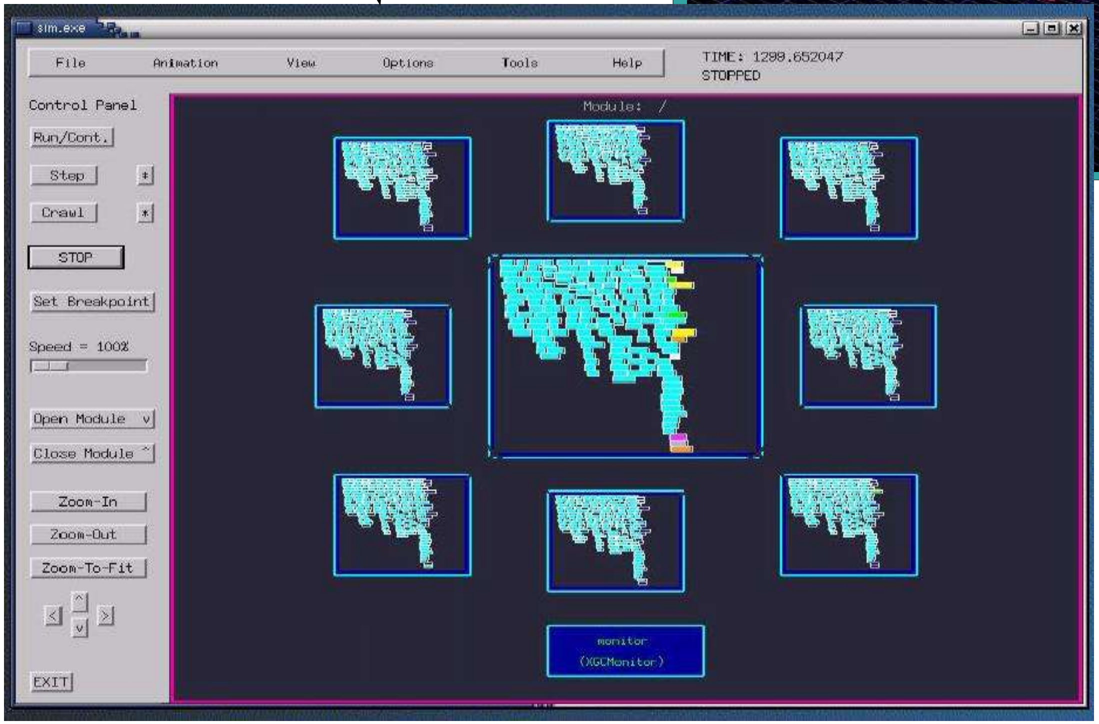


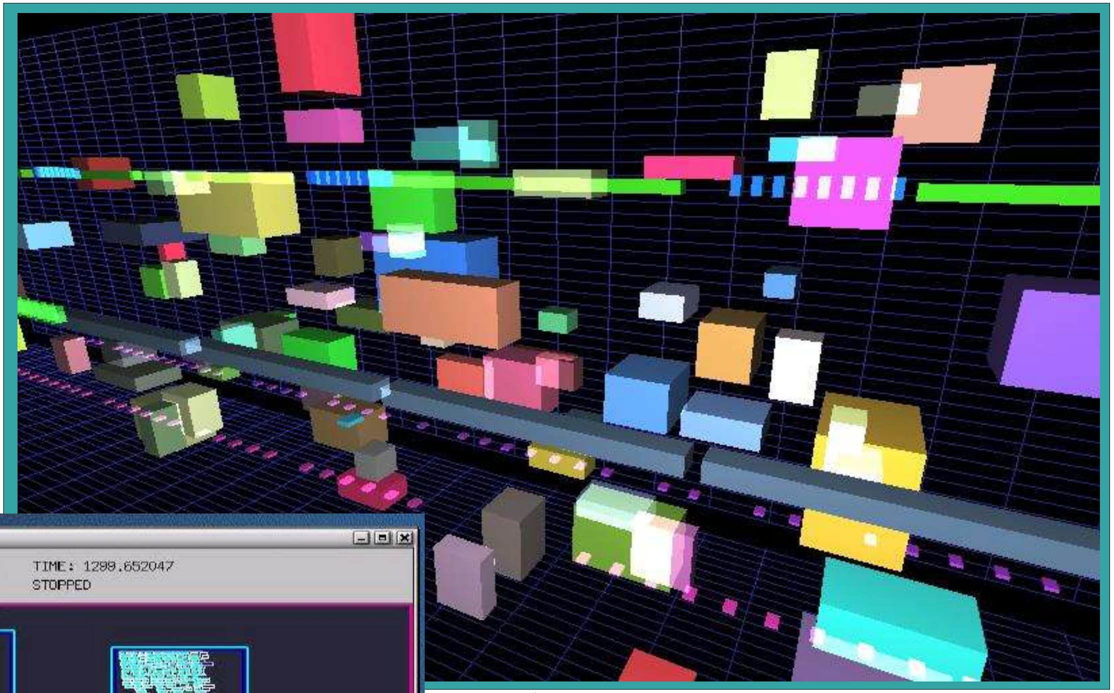


Application Example 2

Spectrum Management

- World models of agents within each radio view show allocations vs. time (horiz.) and vs. freq. (vert.)





- Multi- dimensional view shows allocations in time duration (right- left) vs. location (depth) vs frequency (vertical) and vs priority (color/owner).

Conclusions

General purpose distributed real- time control method.

Advantages:

- Decentralized, continuous operations, real- time.
- Embeddable, lightweight.
- Minimizes central- dispatch communications .
- Improves efficiency, reduces disruptions & response delays.
- Greater scalability than centralized solutions.

Risks:

- New inter- agent communication overhead.
- Convergence, solution quality, stability, limit cycles, chaos.
- Predictability, ability to set bounds.
- The unknown.

Lessons learned:

- Modeling & simulation essential for agent deployment.